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Pocket Gophers in Forest Ecosystems

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and Lewis Nelson, Jr.

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RESEARCH SUMMARY

This publication is a state-of-the-knowledge report on available information on gopher biology, ecology, damage, and control. Habits and related problems are reviewed for gopher species throughout the United States, but attention is focused on the northwestern forest environments. A bibliography containing over 1,000 literature citations is included.

The report is not intended as a field guide for control practices, but is meant to familiarize the land manager with the nature and extent of pocket gophers, damage potential, and available control methods. It also discusses areas where research is needed.

PREFACE

The digging, burrowing, and feeding activities of pocket gophers (Geomyidae) frequently conflict with land management goals. In the Pacific Northwest, gopher depredation to conifer seedlings on forest lands is a particularly important economic concern. The following is a state-of-the-knowledge report on gopher biology, ecology, damage, and control. Gopher habits and related problems are reviewed for geomyid species ranging throughout the United States, but more attention is focused on pocket gophers found in northwestern forest environments. This report is not intended as a field guide for control practices, but is meant to familiarize the land manager with the nature and extent of pocket gopher problems, damage potential, and available control methods.

To facilitate access to existing literature, a bibliography of over 1,000 literature citations is included. This section is expanded from a bibliography compiled by Anderson and others (1976:GR). Citations are designated into categories by subject and listed alphabetically by author. Letter abbreviations are assigned to each subject category, and citations used within the text will be found by referring to the appropriate section.

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IDENTIFYING CHARACTERISTICS

General Description

A number of distinctly subterranean attributes equip pocket gophers (Geomyidae) for their fossorial existence. These qualities developed convergently in at least five completely unrelated lineages. Characteristics other than their morphological adaptations for burrowing include reduced individual movement, distribution patterns that vary with soil conditions, parapatric distribution, and a social system in which individuals rigorously defend lone territories (Patton and Yang 1977:G).

General morphological characteristics include: compact musculature, powerful forearms, long claws on the forefeet, and sharp, curved, continuously growing incisors that aid in digging and burrowing (Tryon 1947:NH; Howard and Childs 1959:HRR; Hall and Kelson 1959:GR; Downhower and Hall 1966:DT). Gopher lips close behind the incisors preventing soil from entering their mouths when foraging and digging. Gophers have small eyes, set wide and high on their heads, and small external ears (fig. 1). Two external, fur-lined, ever-visible cheek pouches used in carrying food and nesting material give the word "pocket" to their name.

Among the three genera within the United States, morphological and ecological characteristics appear to be most generalized in *Thomomys* (Hill 1937:PHM). *Geomys* spp. characteristics connote a higher degree of specialization with a more massive, flattened skull, smaller eyes, inconspicuous ears, and exceedingly prominent forefeet with heavy nail and limb development (Miller 1964:DT).

Guard hairs are sparsely scattered and occur mainly in the rump region on the body and tail. They may function as sensory units to guide the gophers forward and backward through dark tunnels. The almost naked tail and feet may be thermoregulatory and the gophers respond to heat stress by increasing blood flow to these extremities (McNab 1966:GH).

The environment may play a role in fur color. Darker species occur in darker soils and lighter colored populations inhabit drier, lighter colored soils (Ingles 1950:PHM; Getz 1957:PHM; Walker 1955:DT). Gophers uncommonly display color aberrations, although several studies report various instances of pelage color mutations (Storer and Gregory 1934:PHM; McCarley

1951:PHM), including occasional sightings of albinism (LaVoie and others 1971:PHM).

Pocket gophers annually undergo variable and irregular molts. Semiannual molts result in distinctive summer and winter coats (Bailey 1915:DT; Howard and Childs 1959:HRR). Gophers may experience an early summer molt that spreads down to the tail and is evidenced by a "molt line" at various stages (Tryon 1947:NH).

The gophers occasionally produce soft squeaks, and teeth "clicking" may serve as a warning mechanism. The solitary behavior of pocket gophers may not necessitate a more complex system of vocal communication (Howard and Childs 1959:HRR).



Figure 1.—The pocket gopher has small eyes, set wide and high on the head, and small external ears.

Taxonomy

Pocket gophers comprise a highly fossorial group of rodents found only in the Western Hemisphere. They occupy habitat types from sea level to above timberline. Their taxonomy is based mainly on groove patterns of the upper incisors. Classification may be complicated by groove patterns that have developed similarly in different lineages (Akersten 1973:PHM). Within this family, Hall and Kelson (1959:GR) identified eight living genera: *Thomomys*, *Geomys*, *Pappogeomys*, *Cratogeomys*, *Orthogeomys*, *Heterogeomys*, *Macrogeomys*, and *Zygogeomys*. Revised classification schemes detail only five genera, three of which occur within the United States: *Thomomys*, *Geomys*, and *Pappogeomys* (= *Cratogeomys*) (Russell 1968b:DT; Hall 1981:GR) (fig. 2). *Pappogeomys* and *Cratogeomys* are used interchangeably throughout this text, depending on the way individual researchers classified them.

Complex distribution patterns and extreme geographical variation of pocket gophers cause classification difficulties at the species and subspecies levels (Patton 1973:G). The three U.S. genera display varied morphological and ecological requirements. Based on these variations, Hall (1981:GR) identified five species and almost 300 subspecies of *Thomomys* within North America. In addition, he lists seven species and 38 subspecies of *Geomys* and nine species and 54

subspecies of *Pappogeomys*. Only one species of *Pappogeomys* occurs in the United States.

Characteristics of Age, Sex, and Development

Proper sexing and aging is important in the assessment of gopher population dynamics. Investigators generally use characteristics denoting reproductive activity as an indicator of age. Gophers are normally separated into two age classes: young and adults. Researchers have not developed reliable techniques for aging animals beyond 1 year of age (adulthood) (Hansen and Reid 1973:DT).

The presence of a pubic gap in a female generally indicates participation in at least one breeding cycle. The pubic gap forms with the resorption of the pubic symphysis just prior to the first breeding season. At this point the female is termed adult. Investigators term animals lacking such a gap as young (Hisaw 1924:PHM; Miller 1946:RGA; Hansen 1960:RGA). Hansen (1960:RGA) also found the size of the uterine horns to be of limited value in distinguishing young from adults or determining reproductive activity. The horns remain small in young until approximately 6 to 7 months. The presence of placental scars, lactation or enlarged mammary tissue, and size of uterus in nonpregnant females



Figure 2.—General distribution of the three genera of pocket gophers within the United States. Prepared from distribution information in Hall (1981:GR).

give further evidence of past and present reproductive activity (Lay 1978:RGA).

Male aging criteria are more ambiguous. Investigators consider males producing sperm or living through at least one breeding season as adults, and class nonsperm producers as young (Vaughan 1967:DT). The position, size, and condition of the testes often serve to indicate male status (Hansen 1960:RGA; Vaughan 1967:DT; Brown 1971:RGA; Lay 1978:RGA). The length of the baculum also serves as a distinguishing characteristic up to age 7 months (Vaughan 1967:DT). Overall baculum length varies considerable among species (Ingles 1965:DT; Vaughan 1967:DT). Hansen (1960:RGA) provides data on age-length relationships for *T. talpoides* in Colorado.

In Florida, Brown (1971:RGA) distinguished three age groups (juveniles, subadults, and adults) of *G. pinetis* based on body size and condition of molt. Howard and Childs (1959:HRR) also used characteristics of pelage but found it relevant only for the very young. They used body length and weight to age *T. bottae mewa* in California up to age 3 or 4 months. Weights fluctuated widely after that. They distinguished 8- to 10-month-old males from 20- to 22-month-old males using body weights. Body length was more diagnostic for females. Adult males usually weigh more than adult females (Howard and Childs 1959:HRR; Wilks 1963:HRR; Hegdal and others 1965:NH; Best 1973:DT; Reid 1981:RGA).

Difficulty is encountered in the field when trying to distinguish young from adults. Researchers can distinguish between young and adult males by palpation

of the os penis (baculum). Aging of females is considerably easier through external examination of the pubic gap. Distinction becomes increasingly difficult as physical development progresses (Hansen 1960:RGA).

Newborn pocket gophers are blind and naked (Hill 1937:PHM). Andersen (1978:RGA) details developmental characteristics and rate of growth for *T. talpoides* based on laboratory observations (table 1). The average weight at birth of individuals in litters of five was 0.126 oz (3.58 g), while in litters of six, young averaged 0.098 oz (2.77 g) each. Animals apparently reached adult size in 100 days. Reid (1981:RGA) observed that *T. talpoides* in Colorado averaged four young per litter with individuals weighing approximately 0.1 oz (4 g) each at birth. Individuals did not attain a "near-adult" weight of 2.6 oz (75 g) until approximately 180 days. Reid claimed young became vulnerable to trapping at 1.4 oz (40 g) or about 50 days. He suggested the delaying of annual recruitment measurements until fall when all current young attained a trappable size. Barnes (personal communication, 1982), however, believes gophers weighing less than 1.4 oz (40 g) could be captured.

REPRODUCTION

The breeding season for pocket gophers varies throughout their range and depends on physical characteristics of the environment (table 2). Gophers take advantage of abundant food periods to fulfill energy requirements. Both mother and young adapt cycles to maximize survivability. *T. bottae novis* may breed year-round in California. The major reproductive effort, however, takes place in spring, coinciding with a period of abundant green growth and optimum soils for burrowing (Miller 1946:RGA). Andersen and MacMahon (1981:RGA) studied the energy demands of pocket gophers in Utah and energy supplied by various habitat types, and concluded that *T. talpoides* females advantageously delay breeding until a relatively snow-free period when aboveground plants again become available. Reproduction, however, can occur before snowmelt. In a Colorado study, Hansen (1960:RGA) found dead young in snow nests above the ground. Age, microclimate, population characteristics (that is, availability of males), and recent reproductive history can influence the actual time of conception (Desy and Druecker 1979:RGA). An extensive population dynamics study on Colorado rangelands showed that most pocket gophers breed during 4 to 5 months from the beginning of March to the end of June or July (Reid 1973:RGA, 1981:RGA). The majority of births take place between the beginning of May and the end of June. This extended period results from the presence of two classes of reproducing gophers: adults older than a year that bear young first in the spring; and young of the previous year that bear during late spring and summer.

Some studies indicate that breeding or sexual maturity occurs earlier in females than in males (Wilks 1963:HRR; Lay 1978:RGA). However, Tryon (1947:NH) reported that males came into the breeding condition first. The age at which females become a reproductive

Table 1.—Age indicators for captive northern pocket gophers (*T. talpoides*) in Utah¹

Age	Description
Days	
1	Hairless; eyes visible as dark spots under skin; pinnae pinhead-sized buds on side of head.
9	Dorsal pelage grey-black; sparse white ventral hair; both upper and lower incisors gapped; young move about cage predominately using a backward crawl.
16	Incisors gap closed; foreclaws pronounced; pinnae protrude from head; young move about actively.
17	Solid food eaten.
20	Pockets visible but appear closed at exterior; auditory canal closed.
23	Foreclaws 0.16 inches (4 mm) long.
24	Eyes closed; ears probably closed; pockets appear open at exterior; postjuvenile molt in progress—brown replacing grey-black in dorsal pelage.
26	Eyes, ears open.
39	Pouches used to carry food.
60	Fighting among siblings; separation required.
100	Immature molt into adult pelage up to half completed.

¹Reproduced from Anderson (1978:RGA).

Table 2.—Fecundity rates among pocket gophers by area and habitat type

Species	Habitat	Location	Breeding season	Litter size	Number litters/year	Source
<i>Thomomys talpoides</i>	Mountain meadow	Colorado	Mid-March—Mid-May	4-5	1	Hansen 1960:RGA
		Bridger mts., Montana	Mid-April—Mid-May	4.4 \pm .13	1	Tryon 1947:NH
		Utah	Early summer	5-6	1	Andersen and MacMahon 1981:RGA
		Utah	Early summer	3.23	1	Ellison and Aldous 1952:HRR
<i>Thomomys talpoides quadratus</i>	Mountain meadow	Oregon	Spring and early summer	5-10 (6.6)	—	Moore and Reid 1951:HRR
	Fruit orchards surrounded by uncultivated pasture	Oregon	Peak: Mid-March	5-9	2	Wight 1930:RGA
<i>Thomomys bottae</i>	Annual grassland	California	Late Jan.—April	4.6	1-2	Howard and Childs 1959:HRR
	Mountainous area	South central Colorado	March—August	3.5 \pm 1.2	1	Vaughan 1967:DT
<i>Geomys bursarius</i>	Shortgrass prairie	Colorado	April—May	3.5	1	Vaughan 1962:RGA
	Sandhill	Texas	Oct.—June	—	2-3	Wilks 1963:F
	Rangeland	Texas	Feb.—Aug.	2.7	1-2	Wood 1949:RGA
<i>Geomys pinetis</i>	Tampa Bay area	Southern Florida	Year-round Peaks: June—July Feb.—March	1-3 (1.74)	2-3	Brown 1971:RGA

part of the population varies among species and locale. Females reach puberty as early as 3 months (Miller 1946:RGA; Wood 1949:RGA; Wilks 1963:HRR). Brown (1971:RGA) reported *G. pinetis* became sexually mature at 4 to 6 months. Vaughan (1962:RGA) reported an 8-month span prior to puberty for *G. bursarius*.

Limited information exists on gestation. Estimates vary from 18 to 30 days for *Thomomys* (Scheffer 1938:RGA; Howard and Childs 1959:HRR; Reid 1973:RGA). Schramm (1961:RGA) observed gestation to last 19 days for *T. bottae* in the laboratory. Andersen (1978:RGA) determined an 18-day gestation for captive *T. talpoides*.

Adult animals (*Thomomys* spp.) produce only one litter per year on most western range and forest lands. Animals from these litters will not mature sexually until the following year. Reasonably stable reproductive patterns are genetically determined, but age and seasonal environmental conditions can influence fertility (Miller 1946:RGA) (table 2). Litter size varies with locality and habitat type (Wight 1930:RGA; Tryon 1947:NH; Aldous 1957:F; Reid 1973:RGA, 1981:RGA). Females bear from three to more than six young at a time. Numerous authors have reported average litter size (particularly for *Thomomys* spp.) for a variety of habitats (Tryon 1947:NH; Wirtz 1954:RGA; Hansen 1960:RGA; Hansen and Ward 1966:HRR; Youmans 1979:HRF; Andersen and MacMahon 1981:RGA).

Extended breeding seasons may occur in areas with stable climates. *T. bottae novis*, living in the irrigated fields of the Sacramento Valley, bred year-round and produced up to three litters annually with four to six individuals in each (Miller 1946:RGA). In contrast, Miller found that in northern California at higher elevations gophers generally restricted their breeding to spring. *Geomys bursarius* breeds over a longer time in the southern part of its range (Hisaw 1925:PHM). Farther north, females do not usually mature sexually until the year after birth.

Brown (1971:RGA) reported the lowest litter sizes for any species of pocket gopher. *G. pinetis* produced from two to three litters annually with one to three young born in each. This species displayed an unusually low turnover rate. A high rate of survival apparently compensated for low reproduction.

Sexual development, fertility, and nutritional factors often correlate positively. Hansen (1960:RGA) noted an increase in sexual organ development and breeding activity when *Thomomys* diet consisted primarily of alfalfa roots. Miller (1946:RGA) reported significantly more breeding taking place in summer on irrigated land than on nonirrigated. Reproduction depended greatly on soil moisture and green vegetation. On a chemically treated Colorado range, Hansen and Ward (1966:HRR) reported that female pocket gophers produced slightly smaller mean litter sizes than females on untreated

range. Herbicide use reduced broadleaf forb production on the treated range.

DISPERSAL

Weaned pocket gophers may disperse from the nest at about 5 to 6 weeks of age (Miller 1946:RGA; Brown 1971:RGA). Howard and Childs (1959:HRR) reported dispersal of *T. talpoides* at about 8 weeks. Other species (*G. bursarius*) mature sexually as early as 3 months and disperse (Wood 1949:RGA). Young and mother coexist peaceably until increasing agonistic behavior forces dispersal (Wight 1930:RGA). Distances recorded for gophers when dispersing or traveling vary (table 3). Howard and Childs (1959:HRR) noted that some dispersal occurred over the surface. Marked animals traveled at least 400 ft (122 m) before recapture with funnel nets.

Hickman and Brown (1973:B) recorded a maximum dispersing distance of 260 ft (79 m) for *G. pinetis*. The gopher spent at least 20 minutes above ground. Vaughan (1963:M) noted that *T. talpoides* moved up to 1,000 ft (305 m) at a time with an average of 545 ft (166 m). In 1967, Vaughan (1967:DT) compared the distance traveled by released individuals of *T. talpoides* and *T. bottae*. *T. talpoides* moved a mean distance of 785 ft (239 m) although one individual went 2,590 ft (789 m). *T. bottae* dispersed a mean distance of 197 ft (60 m). One individual traveled a maximum of 900 ft (274 m).

Burrowing through snow facilitates pocket gopher dispersal. Animals gain access over obstacles normally blocking movement during snow-free periods (Hansen and Reid 1973:DT). Extensive movement may take place in the snowpack (Hansen 1962:M; Ingles 1949:M).

Gophers may rapidly repopulate control areas, especially when improperly treated (Keith 1961:CHH; Buchner and Rorabaugh 1979:DTF). On the Ashton District in Idaho, overwinter reinvasion occurred on 30-acre (12-ha) clearcuts when surrounding timber was not treated at least 60 ft (18 m) past the clearcut boundary (Birch 1982, personal communication). Uncut buffer strips may slow reinvasion. In Colorado, gophers repopulated fall-trapped 1-acre (0.4-ha) plots by the following summer. Hansen and Reid (1973:HRR) suggested a 200-ft (61-m) buffer zone to prevent reinvasion by gophers burrowing in snow. Gophers also exhibit homing tendencies after displacement (Howard and Childs 1959:HRR).

ECOLOGICAL DISTRIBUTION

In general, unsuitable soil and/or flora types limit pocket gopher distribution. Soil type tolerance, climatic conditions, or intraspecific competition may limit the range of individual species (Miller 1964:DT). McNab (1966:GH) suggested that minor physiological differences between species could influence distribution.

The gophers display physical and behavioral adaptations best suited to their respective habitats (Buchner and Rorabaugh 1979:DTF). Species consequently maintain almost total allopatric or parapatric distributions (Bailey 1927, 1931:GR; Kennerly 1959:DT; Vaughan 1967:DT; Best 1973:DT; Dalquest and Kilpatrick

1973:DT; Bradley and others 1974:PHM). Allopatry generally prevails where ranges meet, although a local population may include different species. Vaughan (1967:DT) described range overlap between *T. talpoides* and *T. bottae* in Colorado. Populations of one species coexisted with individuals or colonies of the other; however, both populations maintained reproductive isolation. Vaughan believed species achieved separation through differences in dispersal abilities and reproductive cycles.

Patton (1973:G) described hybridization occurring among *T. bottae* and *T. umbrinus* in southern Arizona but found no evidence of genic introgression. Sterility in male hybrids coupled with reduced reproductive potential in female hybrids established a "postmating barrier." Patton and Yang (1977:G) hypothesized that chromosomal organization in *T. bottae* was more important than genic variation in events leading to speciation and reproductive incompatibility.

Contiguous allopatry may occur in some areas with the competitive exclusion of one species by another. Miller (1964:DT) found a pattern of hierarchy established among four species of gophers in Colorado. Populations with the largest individuals outcompeted other populations for superior habitat. Tolerance to the soil type dictated a species' ability to compete. Superior species with the most restrictive niche requirements displaced other species to less favorable habitats. Patton (1973:G) observed that *T. umbrinus* appeared limited in distribution as a result of direct competition from larger, more aggressive members of *T. bottae*. However, he suggested that limited soil tolerance and poor physiological adaptability of *T. bottae* prevented them from displacing *T. umbrinus* even further.

In general, larger species are more restricted by soil type and occur at lower elevations in deeper, more tractable soils. Smaller species inhabit higher elevation, and shallower, rocky soils (Davis 1938:PHM; Dalquest and Scheffer 1944:DT). But Tryon and Cunningham (1968:NH) found smaller individuals in deeper, low elevation soils while larger bodied animals inhabited high elevation habitat. In this case, animal size seemed related to population density and the quality of forage in animal diets. Larger species may displace smaller ones where ranges meet (Miller 1964:DT; McNab 1966:GH). In a conflict situation, larger individuals may dominate, but smaller species forced to occupy less favorable habitats may more readily adapt (Howard and Childs 1959:HRR). However, Miller (1964:DT) did not find that larger individuals dominated. *Pappogeomys castanops* was competitively inferior to the smaller members of *G. bursarius*.

Extreme temperatures may limit fossorial rodents in shallow soils (Howard and Childs 1959:HRR; Kennerly 1964:BE). Gophers excavate deeper during hot and dry periods (Crouch 1933:DC; Wilks 1963:HRR). In this way, they may avoid heat stress. Larger animals may burrow proportionately deeper because of their size (Kennerly 1954, 1959:DT; McNab 1966:GH). Howard and Childs (1959:HRR) reported that burrows tended to collapse when constructed in soils averaging 4 inches (10 cm) or less in depth.

Table 3.—Movements and home range sizes among pocket gopher populations

Species	Location	Method	Scope of study	Distance traveled			Home range			Source			
				♂	♀	Juvenile	Average	Maximum	♂		♀	Juvenile	Average
Thomomys Talpoides	Utah experimental forest	Extensive trapping on arranged plots	Annual shifts Over winter			99	10	> 40				Andersen and MacMahon 1981:RGA	
	Colorado: a) Mima mound habitat	Mark recapture with		100	81							Hansen 1962:M	
	b) Thurber-fescue-forb rangeland	maximum distances between captures	Successive captures - snow-free periods	43	83				36			Hansen and Reid 1973:DT	
	Northern Idaho Forb-shrub complex	Radio-isotope tracking	Daily	3	4	4	3-13		356	281	261	606	Kuck 1969:DTF
	Colorado range	Mark recapture					238	785					Vaughan 1967:DT
T. talpoides and T. mazama	Central Oregon Logged-slash burned	Winter cast survey	April					121					Barnes 1974:HRF
	Colorado range	Mark recapture					60	273					Vaughan 1967:DT
Thomomys bottae	California range	Mark recapture	Winter & Spring						818	394			Howard and Childs 1959:HRR
Thomomys monticola	Sierra Nevada mountain meadow			36		121			24-451	27-572	28-572		Ingles 1952:HRR
Geomys pinetis		Captured and release					78						Hickman and Brown 1973:B

Pocket gophers prefer light, friable, well-drained soils. They select porous, sandy soils. Clay types may be too compact for burrowing. (Davis and others 1938:S; Davis 1940:DT; Kennerly 1954:DT, 1958:NH, 1964:BE; Howard and Childs 1959:HRR; Wilks 1963:HRR; Miller 1964:DT; Andersen and MacMahon 1981:RGA). Andersen and MacMahon (1981:RGA) proposed differences in "burrowing efficiency" as opposed to agonistic displays of behavioral dominance as the best explanation for parapatry among pocket gophers.

Gophers may live in soils where mean moisture content ranges from less than 10 to more than 50 percent (Hansen and Beck 1968:HRR). Andersen and MacMahon (1981:RGA) noted that *T. talpoides* apparently could not dig in dry, compact soils and showed aversion to burrowing in wet soils. Burrowing became impossible when moist soils froze. Youmans (1979:HRF) noted that swales in Montana contained too much moisture for gopher inhabitation until late summer. Dispersing juveniles would then establish territories in those areas. Ingles (1949:M) noted that pocket gophers abandoned burrows during active snowmelt and/or runoff. Narrow strips of wet, soggy soil often acted as barriers to dispersal.

Pocket gophers require high rates of gas exchange in their burrows (Kennerly 1964:BE; McNab 1966:GH). Clay soils with high water-holding capacity may not permit an adequate exchange of oxygen and carbon dioxide (McNab 1966:GH).

Chemical properties of the soil may not directly affect pocket gopher distribution except through modification of existing soil structure and plant composition or production. Soil fertility may become increasingly important as it affects the presence or absence of preferred vegetation (Hansen and Reid 1973:DT). Davis (1938:PHM) placed little importance on soil pH.

Patterns of distribution reflect other physiological and morphological adaptation by gophers to their environments. Bradley and others (1974:PHM) compared metabolic rates and thermal conductance between mountain meadow dwelling species (*T. talpoides*) and gophers (*T. umbrinus*) living in the deserts of Nevada. The smaller size, longer tails, and reduced insulation of *T. umbrinus* contributed to lower metabolic rates and higher thermal conductance. The investigators felt these adaptations to different environmental conditions explained their ecological distributions.

BEHAVIOR

Food Habits

Pocket gopher food preferences show marked geographic variation. Strictly herbivorous gophers use all the plant parts during the course of active year-round feeding (Ward 1973:FF). Aldous (1951:FF) reported pocket gophers feeding in the immediate vicinity of their mounds but could not determine how far gophers ranged to forage aboveground. Ward (1960:FF) noted that pocket gophers gathered aluminum-coated grain on the surface, indicating that aboveground foraging may be more extensive than previously thought. The

Colorado Cooperative Pocket Gopher Project (1960:DT) also documented aboveground feeding in summer.

Tryon and Cunningham (1968:NH) believed gophers could "select" foods based on proportionately higher quantities of proteins and fats found in their stomachs than in habitat vegetation. Some species select and rely on forbs, as indicated by studies in Colorado (Keith and others 1959:DC; Ward 1960:FF; Ward and Keith 1962:FF; Vaughan 1967:FF; Turner 1973:HRR), Montana (Tryon 1947:NH), Oregon (Moore and Reid 1951:HRR), and Utah (Aldous 1951:FF). Grasses, even if abundant, often comprise only a minor proportion of *Thomomys* diet (Ward 1973:FF). In feeding trials of *T. talpoides*, Teitjen and others (1967:HRR) reported that only those grasses high in moisture content or with food storage structures could provide diets capable of sustaining gophers. Vaughan (1967:FF) said grasses comprise 72 percent of the vegetation in his Colorado study area, but composed only 30 percent of the annual diet for *T. talpoides*.

In south-central Oregon, *T. mazama* preferred the annual forbs that comprised 57 percent of the vegetative cover, but they subsisted on perennial grasses when forbs were not available (Burton and Black 1978:FF). Preferred forbs include common dandelion (*Taraxacum officinale*), lupine (*Lupinus* spp.), penstemon (*Penstemon rydbergii*), western yarrow (*Achillea millefolium lanulosa*), agoseris (*Agoseris* spp.), hairy goldaster (*Chrysopsis villosa*), slenderleaf gilia (*Gilia linearis*), aspen peavine (*Lathyrus leuconthus*), fremont geranium (*Geranium fremontii*), and beauty cinquefoil (*Potentilla pulcherrima*) (Ward 1960:FF, 1973:FF; Hansen and Ward 1966:HRR).

Forbs and shrubs constituted 67 percent of the annual diet on shortgrass prairie in Colorado. Pocket gophers relied most heavily on pricklypear (*Opuntia polyacantha*), which serves as a primary source of nutrition and water. A combination of weather and intensive gopher consumption of pricklypear probably influences local abundance of this plant (Vaughan 1967:FF). On forest lands in California, *T. monticola* preferred lupine but consumed proportionally high quantities of whitethorn ceanothus (*Ceanothus cordulatus*), gooseberry (*Ribes roezoli*), and some red fir (*Abies magnifica*) (Buchner and Rorabaugh 1979:DTF).

Pocket gophers are adaptable in their feeding habits, and food preferences are responsive to changes in the availability of forage species (Ward 1973:FF; Burton and Black 1978:FF). They primarily select green, succulent, aboveground leaves and stems during the growing season. Depending on the habitat, underground plant parts, roots, or grasses become most important during the dormant season (Ward 1960:FF; Myers and Vaughan 1964:FF; Burton and Black 1978:FF).

The variable feeding preferences of pocket gophers do not preclude any plant species from attack in certain situations (Canutt 1970:DTF; Working Group of the Northwest Forest Pocket Gopher Committee 1976:DTF; Crouch 1979:DC). Studies of gopher preferences for specific conifer species showed weak correlations or none at all. Crouch (1971:DTF) found no significant difference in gopher preference among ponderosa pine (*Pinus*

ponderosa), jeffrey pine (*P. jeffreyi*), and lodgepole pine (*P. contorta*).

Andersen and MacMahon (1981:RGA) studied energy requirements of *T. talpoides* and relationships between forage availability in different environments along a successional gradient. The species displayed catholic food habits and ate anything nonnoxious. High energy costs of securing foods made these actions seem reasonable.

Pocket gophers store food in lateral tunnels that branch from the main runway. These food caches may exceed their needs (Ward 1973:FF). Ward located the caches of *T. talpoides* in Colorado 3 to 4 inches (8 to 10 cm) below surface. Idaho studies on *T. talpoides* showed caches to be deeper, usually from 7 to 12 inches (17 to 30 cm).

Activity Periods

Gophers remain active year-round (Scheffer 1931:B; Hansen and Reid 1973:HRR; Andersen and MacMahon 1981:RGA). In temperate regions, gophers appear to be most active during spring and fall (Scheffer 1931:B; Criddle 1930:NH). In drier areas, activity peaks during the rainy season (Miller and Bond 1960:B). Miller (1948:B, 1957:BE) found digging activity related to soil moisture in the Sacramento Valley and other climatologically similar regions. Activity remains lowest in summer and early fall, then rises abruptly after the first heavy autumn rains. Kuck (1969:DTF) used radioisotope labeling on gophers to follow their activities throughout the summer. He noted that activity occurred 24 hours a day but intensified during daytime. He also related intensified seasonal activity with increased soil moisture. More active females and juveniles moved farther than adult males.

Miller and Bond (1960:B) discovered that mountain populations of *T. talpoides* remained inactive in late spring and summer during presumably ideal soil moisture and burrowing conditions. Seasonal activities appeared to be the result of changes in breeding behavior and feeding habits.

Howard and Childs (1959:HRR) found that pocket gophers maintained deeper burrows during hot, dry summer conditions. They observed some gophers in a "profound sleep" under laboratory conditions. They speculated that *Thomomys* might undergo a period of torpidity when conditions become exceedingly warm or dry. Kuck (1969:DTF) found that radiotracked gophers often became inactive for long periods during late summer. Some underwent a period of estivation. One adult male remained inactive for 13 days in mid-August.

The literature contains limited knowledge of daily activity patterns of pocket gophers. Andersen and MacMahon (1981:RGA), employing radiotelemetry, found *T. talpoides* remaining active during all hours of the day. They could not define the type of activity being performed but assumed gophers spent 50 percent of each day in nonresting. Two weeks of continual monitoring revealed that individuals spent approximately 34 percent of their time in activity (Vaughan and Hansen 1961:PHM). Tryon (1947:NH), finding that *T. talpoides* in Montana excavated about 60 percent more soil at

night, deduced that most activity probably occurred at dawn and at dusk. Hungerford (1976:FF), however, disclaimed reliance on surface sign as an indicator of total daily activity patterns based on laboratory findings. Mound building occurred most frequently in the morning and at night. Other activities took place around the clock with intermittent rest. Gophers, when secure in their burrows, may not leave any aboveground sign for months. Kuck (1969:DTF) found activity varied throughout the summer, although the actual distances traveled by gophers did not change. Evidence indicated that activity did not correlate with seasonal movement. Environmental conditions influenced daily activity but not total distance traveled to defend territory. In addition to defense, movement in search of food may continue regardless of environmental conditions.

Territoriality

Pocket gophers actively defend individual territories most of the year. Their home ranges usually correspond with the burrow system. Kuck (1969:DTF) and others noted that home ranges tend to be linear in shape, with activity usually concentrated in certain portions of the territory. Hansen and Remmenga (1961:F) found that relationships existed between pocket gopher densities and the size and distribution of territories. At low populations, territories remained clustered with a good deal of vacant land between colonies. At intermediate densities individual territory size approaches a normal distribution. A regular distribution pattern with territories similar in size existed at high densities.

Males generally maintain larger territories than females (Kuck 1969:DTF). In California, Howard and Childs (1959:HRR) estimated that burrow systems covered 8,860 ft² (823 m²) for males and 4,260 ft² (396 m²) for females. Larger territories existed when population densities were lower. On Black Mesa, open tunnel length for *T. talpoides* ranged from 80 to 105 ft (24 to 32 m). Individual burrow systems could cover some 6,530 ft² (600 m²) (Hansen and Reid 1973:HRR).

Dispersing subadults quickly take over vacated burrow systems. Young animals looking for a home site may occupy marginal habitats until better areas become available when older animals die or move. Howard and Childs (1959:HRR) believed that *T. talpoides* established territories for a lifetime in the California foothills where snow is uncommon. Hansen and Reid (1973:DT) noted that gophers abandoned belowground territories during Colorado winters and burrowed solely in the snowpack. When forced back to their subterranean habitats, gophers did not necessarily return to previously occupied burrows. Similarly, gophers displaced by snowmelt and rising groundwater tables did not always return to their original systems.

Gophers become tolerant enough of one another to intermix in individual burrow systems only during the breeding season. Investigators most often recorded plural occupancy of burrow systems by the same species during this time (Miller 1946:RGA; Hansen and Miller 1959:B; Howard and Childs 1959:HRR; Vaughan 1962:RGA). Plural occupancy involving two adult in-

dividuals of different species happens less often. Vaughan (1967:DT) reported three separate cases of multispecies occupancy in Colorado. He concluded that inter- and intraspecific tolerance did not differ during periods of breeding.

BURROW SYSTEMS

Numerous authors describe the burrow systems of various species (Scheffer 1931:B, 1940:BE; Tryon 1947:NH; Smith 1948:BE; Downhower and Hall 1966:DT; Hansen and Reid 1973:HRR; Hickman 1977:BE). Best (1973:DT) compared and contrasted characteristics of tunnel systems and mounds of *T. bottae*, *P. castanops*, and *G. bursarius*. He felt confident in identifying species' presence by observing mounds and other ground surface features.

Generally, main tunnels run parallel to the ground. Downhower and Hall (1966:DT) classified them as either "deep" or "subsurface." Main tunnels contain numerous lateral branches that often terminate at the surface in characteristic fan-shaped mounds.

Tunnel diameters vary between 2 and 4 inches (5 and 10 cm) depending on species and animal size (Scheffer 1940:BE; Smith 1948:BE; Moore and Reid 1951:HRR; Best 1973:DT; Hansen and Reid 1973:DT). Best (1973:DT) used tunnel diameter coupled with depth and shape characteristics to distinguish burrow systems of different species.

"Plugs," although difficult to see, also indicate gopher presence. Plugs remain after gophers seal feeding tunnels or repair open breaks in their burrows at ground level (Hansen and Reid 1973:DT; Buchner and Rorabaugh 1979:DTF).

Pocket gophers use subsurface tunnels for feeding. Such tunnels usually occur in the top 4 to 12 inches (10 to 30 cm) of soil. Soil and vegetation structure may control tunnel depth (Davis and others 1938:S; Moore and Reid 1951:HRR; Downhower and Hall 1966:DT; Hansen and Reid 1973:DT). Tryon (1947:NH) reported *T. talpoides* constructed feeding burrows 12 to 16 inches (30 to 40 cm) below patchy areas of sagebrush. Tunnel length varies and can run several hundred feet in all (Moore and Reid 1951:HRR; Downhower and Hall 1966:DT). Richens (1966:B), following and recording the activities of one *T. talpoides* released in Utah, noted that this gopher constructed 480 ft (146 m) of feeding tunnels over 5 months. Tryon (1947:NH) believed pocket gophers could maintain a maximum of 150 to 200 ft (45 to 60 m) of feeding tunnels. Food availability in an area may partially determine the degree of burrowing activity (Scheffer 1931:B; Moore and Reid 1951:HRR).

Deep tunnels often lead to nests and may attain depths of 5 ft (1.5 m) or more (Moore and Reid 1951:HRR). Nests are usually chambers lined with dry leaves and grasses (fig. 3). In Kansas, Downhower and Hall (1966:DT) noted that gophers did not construct nests at the deepest point of the burrow system. A run usually extended deeper from a chamber, suggesting that it may serve to drain other portions of the burrow system.

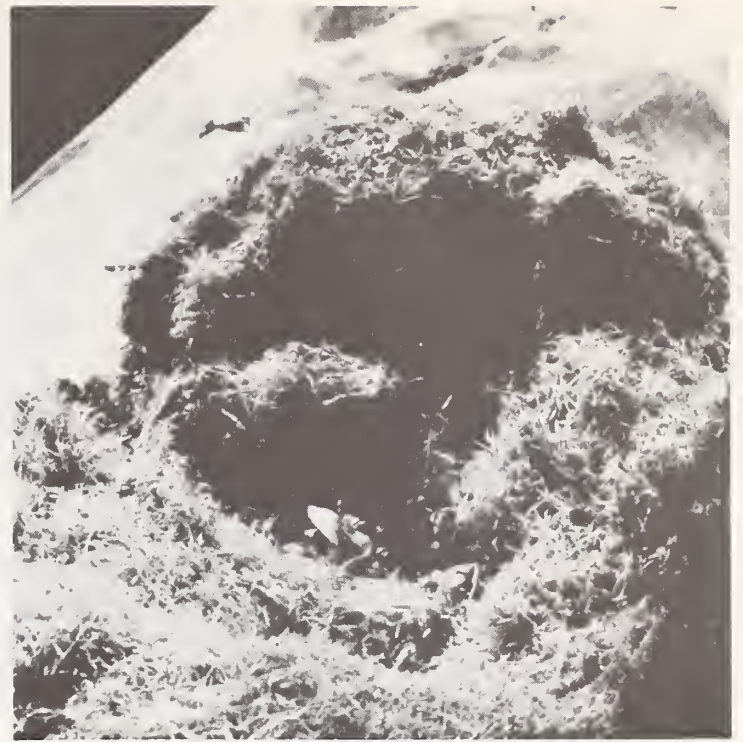


Figure 3.—A winter nest made by the gopher under the snow.

Gophers burrow through the snowpack in winter (Scheffer 1931:B; Ellison 1946:S; Tryon 1947:NH; Miller 1948:B; Ingles 1949:M, 1952:HRR; Hansen and Reid 1973:DT). Snow tunnels may reach a length of more than 100 ft (30 m) (Ingles 1949:M; Hansen and Reid 1973:DT). Gophers form soil casts by pushing soil up from their burrow system into tunnels dug in the snow. These cylindrical casts settle to the ground during spring snowmelt, leaving evidence of winter activity (Hansen and Reid 1973:DT) (fig. 4).

Several reports discuss the microenvironment of the burrow system including characteristics of temperature, light, and humidity. Past research includes: the effects of microclimate on thermoregulatory capacities of pocket gophers (Kennerly 1964:BE; McNab 1966:GH; Gettinger 1975:PHM); comparison of metabolic and thermoregulatory patterns between desert and mountain species of *Thomomys* (Bradley and others 1974:PHM); and examination of the physiological and morphological differences and adaptation of one species in two distinct environments. Andersen and MacMahon (1981:RGA) related features of microclimate and metabolic rates to the energy requirements of *T. talpoides* and subsequent survival limitations.

Other animals will use the gopher burrow systems, but the extent of interaction between gophers and other species remains unclear. Hickman (1977:BE) lists the parasitic and nonparasitic invertebrates, amphibians, reptiles, and small mammals found in these systems and discusses some interactions observed in the laboratory.

Vaughan (1961:BE) recorded 22 species of vertebrates using geomyid burrows for shelter, protection, or as access routes for feeding. He noted that geomyid rodents and tiger salamanders (*Ambystoma tigrinum*) appear to be tolerant of each other. In fact, the existence of the



Figure 4.—Winter casts are left intact as the snow melts.

salamander in certain semiarid habitats may be dependent on the presence of burrows. In other instances, gophers and other animals may compete directly for food and space (Turner 1973:HRR).

ABUNDANCE AND POPULATION FLUCTUATION

Pocket gopher populations may change due to the effects of weather, soil, flora, recruitment, competition, diseases, natural enemies, and land use practices (Frank 1975:DC; Turner and others 1973:HRR; Anderson 1976:HRF). Because geomyids are so adaptable in their feeding habits, plant composition and abundance are probably the primary regulators of gopher density in a habitat (Walker 1949:DT; Moore and Reid 1951:HRR; Keith and others 1959:DC; Turner and others 1973:HRR; Barnes 1974:HRF; Buchner and Rorabaugh 1979:DTF). Gopher densities usually increase on lands disturbed by fire, roadbuilding, logging, site preparation, or other events that open the canopy or disturb the soil. Preferred early successional forbs and grasses often thrive in these areas (Crouch 1969:DTF; Volland 1973:HRF; Anderson 1976:HRF; Capp 1976:DTF; Bur-

ton and Black 1978:FF), and this may increase the carrying capacity in gopher-occupied areas or may encourage the establishment of new populations (Barnes 1974:HRF).

Andersen and MacMahon (1981:RGA) studied populations of *T. talpoides* in four stages of a montane sere ranging from subalpine forb meadow to climax Engelmann spruce (*Picea engelmannii*) forest. Usable plant energy decreased with each successive stage. The availability of palatable underground vegetation correlated with the rodent populations. Climax spruce forest could not meet their year-round energy requirements, and intermediate seral stages were not likely to meet the energy needs associated with reproduction in females. In early seral stages, Andersen and MacMahon (1981:RGA) thought weather patterns that restricted burrowing efficiency influenced population growth more than the abundance of food.

Pocket gophers avoid areas with heavy brush, slash, or deep shade (Buchner and Rorabaugh 1979:DTF). Overstory removal that leads to brush encroachment and limits herbage growth also discourages gopher inhabitation (Barnes 1974:HRF). Similarly, when herbicide treatments reduce vegetation, significant reductions in

gopher densities follow (Howard and Childs 1959:HRR; Keith and others 1959:DC; Hansen and Ward 1966:HRR; Tietjen and others 1967:HRR).

Population densities may not directly relate to elevation, but soil and vegetation, as they vary with altitude, influence them indirectly (Best 1973:DT; Reid 1973:RGA). Tryon and Cunningham (1968:NH) compared an alpine population of *T. talpoides* with one existing 2,200 ft (670 m) lower. Fewer animals occupied the high elevation habitat. Forage, however, was of a higher quality in the alpine zone and individuals there were larger.

Abundance

Anderson (1976:HRF) characterized *T. talpoides* populations in their Oregon habitats with 19 variables measured on 157 sites. Gopher activity and numbers caught increased with elevation and slope and in more mesic conditions. A large number of forbs in disturbed areas provided the best habitat. In Yellowstone National Park, Youmans (1979:HRF) studied populations of *T. talpoides* and relationships to vegetation, soil texture, soil moisture, and snowmelt phenology. His data suggested that soil depths and temperatures, not forb pro-

duction, primarily limited gopher densities. Soil moisture limited their distribution.

Volland (1973:HRF) describes preferences of pocket gophers for certain habitat types in central Oregon. He divided 1,798,900 acres (728 000 ha) into 23 identifiable community types then consolidated the communities into three classes: moderate to high incidence of gophers; low incidence, but a great potential for occupancy; and little activity. Most preferred communities were lodgepole pine sites supporting lush stands of long-stolon sedge, forbs, or both. Gopher activity in natural nondisturbed stands was minimal or nonexistent.

Irregular and rapid fluctuations commonly occur in the rodent populations from year to year (Ingles 1952:HRR; Tietjen and others 1967:HRR; Tryon and Cunningham 1968:NH; Julander and others 1969:HRR; Andersen and MacMahon 1981:RGA). However, populations exhibit a relative degree of stability over time that is often attributed to intraspecific territorial behavior (Howard and Childs 1959:HRR; Hansen 1962:M; Vaughan 1967:DT). Andersen and MacMahon (1981:RGA) hypothesized that intraspecific competition suppressed growth in subalpine populations when they reached some threshold density. Maximum densities vary with locale (table 4), but studies show *T. talpoides*

Table 4.—Late summer and fall pocket gopher densities by area and habitat type

Species	Habitat	Location	Number years censused	Density (individuals/ha)			Source
				Range	Max.	Mean	
<i>Thomomys talpoides</i>	Mountain meadow	Bridger Mts., Mont.	1	—	74		Tryon 1947:NH
		Beartooth Mts., Wyo. (Canadian Zone Sta.)	6	15-44	44		Tryon and Cunningham 1968:NH
		Grand Mesa, Colo.	9	20-52	52	37	Reid 1981:RGA
		Black Mesa, Colo.	15	12-79	79	52	Ibid.
		Wasatch Mts., Utah	2	67-96	96		Richens 1965:PD
	Aspen-dominated forest	Bear River Mts., Utah	3	10-62	62		Andersen and MacMahon 1981:RGA
		Utah	3	2-35	35		Ibid.
		Subalpine fir forest	3	0-10	10		Ibid.
	Engelmann spruce climax	Utah	3	0-2	2		Ibid.
	Grazed ponderosa pine bunchgrass	Colorado	7	—	—	10	Reid 1973:RGA
<i>Thomomys monticola</i>	Ungrazed	Colorado	7	—	—	22	Ibid.
	Mountain meadow	Sierra Nevada Mts., Calif.	4	10-36	36		Ingles 1952:HRR
<i>Thomomys bottae mewa</i>	Annual type range	California	6	49-101	101		Howard and Childs 1959:HRR
<i>Geomys breviceps</i>	Open pasture	Eastern Texas	1	—	17 ^a	3	Davis and others 1938:S

^aThis maximum density is based on a report they note from another study in the same area.

populations consistently peak at between 24 and 36 individuals per acre (60 to 90 per ha). (Andersen and MacMahon 1981:RGA).

Density-independent factors most likely regulate population densities below peak levels.

Longevity, Age, and Sex Structure

Andersen and MacMahon (1981:RGA) did not find fertility rates to vary with density, and attributed variation in population levels wholly to factors influencing mortality rates. Longevity varies among gophers. Maximum lifespans range from 3 to 5 years with an average close to 2 years (Ingles 1952:HRR; Reid 1973:RGA). Young-of-the-year may replace 75 percent or more of the population annually (Tryon 1947:NH; Hansen 1960:RGA; Youmans 1979:HRF).

Juvenile survivorship strongly impacts population densities (Vaughan 1967:DT). In the Pacific Northwest, juveniles comprise a greater percentage of the population in fall (Youmans 1979:HRF) while adults constitute a larger proportion in spring and summer (Tryon 1947:NH; Hansen and Ward 1966:HRR) (table 5). In Colorado, Reid (1973:RGA) found a general correlation between the age structure in fall and gopher density the following year. Increased adult body weights and high

juvenile populations in fall (greater than 50 percent) usually indicated high densities the following year. Conversely, when fall populations exhibited a preponderance of adults (greater than 50 percent), abundance tended to decline the next year.

Rising ground water tables during snowmelt create the period of greatest vulnerability for young (Vaughan 1967:DT; Hansen and Reid 1973:DT). Populations showed abrupt declines when adverse snow conditions resulted in poor juvenile recruitment. Reid (1981:RGA) suggested that the water content of the snowpack and the date at which snowmelt was complete could be used to indicate population trends.

Male to female sex ratios vary in gopher populations and usually relate to the sampling season (Howard and Childs 1959:HRR). Estimates often show a preponderance of adult females to adult males, with juvenile ratios generally more balanced (Wood 1949:RGA; Hansen 1960:RGA; Lay 1978:RGA; Andersen and MacMahon 1981:RGA) (table 6).

Andersen and MacMahon (1981:RGA) hypothesized that males may experience higher mortality because of increased activity during the breeding season, resulting in prolonged exposure to wet, saturated soils. Brown (1971:RGA), studying *G. pinetis* in Florida, believed males travel aboveground to search out females for

Table 5.—Age structure of pocket gopher populations

Species	Number years sampled	Time of sampling	Percent adults	Percent juvenile	Total number of gophers sampled	Source
<i>Thomomys talpoides</i>	15	Fall		57	2,531	Reid 1981:RGA ^a (Black Mesa)
	5	Fall		64	1,083	Ibid. (Grand Mesa)
	1	June		7	69	Youmans 1979:HRF
		Aug.		78	9	
		Sept.		80	64	
	4	Year round during snow-free periods		34	1,738	Hansen 1960:RGA
	4	June Aug. Sept.		14 55 72		Tryon 1947:NH
<i>Geomys pinetis</i>	1	(Monthly May-April)				Brown 1971:RGA ^b
		July	48.2		505	
		Oct.	67.4			
		Feb.	82.4			
<i>Geomys bursarius</i>	3	Monthly total		23	1,218	Vaughan 1962:RGA
		Aug.-Dec.		48		
		Feb.		40		
	1	Sept.		42.3	585	Wood 1949:RGA ^c
		Nov.		3.3		
		Dec.		0		

^aGenerally, young of the year dominated in fall populations and their densities often determined population sizes—particularly in years when they were near the mean high population level.

^bBrown distinguishes 3 age classes: adults, subadults, and juveniles.

^cThis figure includes females only.

Table 6.—Sex ratio for different populations of pocket gophers

Species	Number years censused	Time of sampling	Percent males			Number sampled	Source
			Adult	Juvenile	Adult and juvenile combined		
<i>Thomomys talpoides</i>	9	July-Sept.	54.4			68	Ellison and Aldous 1952:HRR
				53.4		116	
	4	Early summer breeding season	32.3	50 ^a		129	Andersen and MacMahon 1981:RGA
	4	Fall: (12-32 gophers/acre)		50	42	2,531	
	11	Fall: (40-79 gophers/acre)		50	54		Reid 1981:RGA ^b
	5	Fall		50	47	1,083	
	4	Year-round during snow-free periods	47			1,157	
<i>Thomomys bottae</i>				43		376	Hansen 1960:RGA
<i>Thomomys bottae</i>	1	April - May			37	505	Lay 1978:RGA
			26			199	
				45		406	
<i>Geomys bursarius</i>	1	Sept. - Aug.	40.4 ^c	44.8		561	Wood 1949:RGA
	3	Monthly: May - Aug.		51	43	1,218	Vaughan 1962:RGA
						125	
<i>Geomys pinetis</i>	1	Monthly: May - April	40		44	505	Brown 1971:RGA
						339	
				51		166 ^d	

^aSex ratios "believed" equal prior to the breeding season.^bFemales were significantly more abundant at low population levels and males were more abundant when densities were at higher levels.^cThis figure combines data for adults and subadults.^dThis represents combined data for juveniles and subadults.

mating and become more susceptible to predation. Males moving farther and occupying larger territories than females may influence capture and sex ratio estimates (Howard and Childs 1959:HRR).

Lay (1978:RGA) found significantly more females than males among *T. bottae* of breeding age and suggested the existence of polygyny. Male mortality may increase if polygyny leads to increased intraspecific aggression among males competing for females. In an earlier study, Howard and Childs (1959:HRR) discussed polygyny in *T. bottae mewa* and formulated similar conclusions.

Data collected in Colorado over several years revealed more adult females than adult males present during low population years (Reid 1981:RGA). Males dominated sex ratios during high population years. Young-of-the-year demonstrated a mean sex ratio of 50:50 for all observed years.

Hansen (1960:RGA) found an abundance of males and lower susceptibility of pregnant females to trapping during the early spring. However, as indicated by capture, females comprised a greater segment of the population later in the summer. Hansen concluded that females increase their activity when engaged in postnatal care of

the young and become more susceptible to trapping. Balanced sex ratios generally existed at other times of the year.

Predation

Pocket gophers fall prey to a number of avian, mammalian, and reptilian species (Hegdal and Gatz 1976:BE), but predators alone do not have a significant influence on gopher densities (Tryon 1947:NH; Howard 1953:DC; Howard and Childs 1959:HRR). Weasel (*Mustela* sp.) invasion of gopher territory may slow population growth or even contribute to a decline, but weasel impact in regulating density is thought to be minimal (Hansen and Ward 1966:HRR; Andersen and MacMahon 1981:RGA). Coyote (*Canis latrans*) predation, studied for its role in possible biological control, apparently did not influence the rodent populations (Colorado Cooperative Pocket Gopher Project 1960:DT). Other mammalian predators include ermine (*M. erminea*), foxes (*Vulpes* spp.), bobcat (*Lynx rufus*), badger (*Taxidea taxus*), skunks (*Mephitis* spp. and *Spilogale putorius*), and grizzly bear (*Ursus arctos horribilis*) (Moore and

Reid 1951:HRR; Downhower and Hall 1966:DT; Hansen and Ward 1966:HRR; Reid 1973:RGA).

Common avian predators include great horned owl (*Bubo virginianus*), red-tailed hawk (*Buteo jamaicensis*), Swainson's hawk (*B. swainsoni*), common barn-owl (*Tyto alba*), great gray owl (*Strix nebulosa*), long-eared owl (*Asio otus*), burrowing owl (*Speotyto cunicularia*), northern goshawk (*Accipiter gentilis*), and American kestrel (*Falco sparverius*) (Fitch and others 1946:PM; Tryon 1947:NH; Howard and Childs 1959:HRR; Downhower and Hall 1966:DT; Hansen and Ward 1966:HRR; Marti 1969:PM).

Noted reptilian predators include the bullsnake (*Pituophis sayi*) (Hisaw and Gloyd 1926:PM), gopher snake (*P. melanoleucus*), and rattlesnake (*Crotalus* spp.), but other species may also take gophers (Reid 1973:RGA).

Parasites

Although pocket gophers host numerous species of internal and external parasites, there is little concern to public health, and infestation does not generally affect gopher population levels (Tryon 1947:NH; Reid 1973:RGA).

Ectoparasites include mites and ticks (*Acarina*), lice (*Mallophaga*), and fleas (*Siphonaptera*) (Miller and Ward 1960:PD; Price 1972:PD; Tuszyński and Whitaker 1972:PD; Rust 1973:PD). The degree varies to which ectoparasites show host-specificity to pocket gophers (Miller and Ward 1960:PD). Because these rodents lead relatively solitary lives in subterranean environments, transfer of ectoparasites to other animals is minimized. Characteristics of gopher molt and grooming behavior may further restrict parasitic distribution (Rust 1973:PD).

Internal parasites include roundworms (*Nematoda*), tapeworms (*Cestoda*), and some protozoa (Tryon 1947:NH; Todd and Lepp 1971:PD). Liver parasites

(*Capillaria hepatica*), most often prevalent in high density gopher populations, can cause significant atrophy of the liver (Tryon 1947:NH; Tryon and Cunningham 1968:NH).

POPULATION ESTIMATION

Surface Sign

Investigators use surface signs such as mounds, earth plugs, and soil casts as indices to gopher burrowing activity and abundance (Miller and Bond 1960:B; Richens 1965:DC; Reid and others 1966:PE) (fig. 5). Numbers of fresh mounds per acre (hectare) or per mile (kilometer) of transect can denote relative abundance of the animals on a unit area (Phillips 1936:HRR; Mohr and Mohr 1936:B; Julander and others 1959:HRR; Hansen and Ward 1966:HRR). Mound counts can also indicate damage potential on a site and the necessity for control efforts.

Beck and Hansen (1966:PE) detailed a method of expressing gopher abundance based on frequency of mounds along transects. Richens (1965:DC) derived an index to population density based on a simple program of trapping and mound counts. High correlations existed between gopher density and the number of fresh mounds observed bimonthly throughout the summer. Cumulative mound counts made annually in early August also correlated with gopher abundance. A poor relationship existed between population levels and mounds constructed in short 72-hour periods. Reid and others (1966:PE), however, found a significant correlation between numbers of pocket gophers and the number of fresh mounds and earth plugs appearing on sample plots in 48-hour periods. All mounds and earth plugs on sample plots were initially erased by flattening, then 48 hours later all new mounds and plugs were counted. Immediately after this, each plot and 20 ft (6 m) of surrounding buffer zone were saturated with kill traps to



Figure 5.—(A) Earth plugs are one of the surface signs of gopher activity. (B) Fresh mounds can be observed during the summer and fall.

determine the number of active pocket gophers present. It is important to determine this animal-to-sign relationship for each different area because the amount of surface sign per gopher may vary with time of year, herbage composition, and gopher species. Sample plots trapped should encompass the burrow systems of several animals. Sign counting to inventory pocket gophers should take place after young-of-the-year disperse and establish burrow systems, usually in late summer and early fall. In Montana, Youmans (1979:HRF) placed limited value on mound counts to census gophers prior to late July. The advantages of sign counting include minimum site disturbance, rapid analysis, and relatively few worker-hour requirements (Reid 1973:RGA).

Trap-Outs

Trap-out techniques arrive at population counts more directly by attempting to capture all animals on a unit (Ingles and others 1949:PE; Howard and Childs 1959:HRR; Richens 1965:DC). Fall trapping produces the most accurate estimates after young attain trap-pable size (Reid 1981:RGA). The advantages of this technique include count accuracy and rodent availability for immediate examination (Reid 1973:RGA).

Winter Soil Casts

Winter soil casts evident after snowmelt may provide an index to populations prior to reproduction in early summer (Richens 1965:DC; Reid and others 1966:PE; Reid 1981:RGA) (fig. 6). Youmans (1979:HRF), however, reported soil casts represented summer and fall populations the previous year but did not indicate current spring densities. Erroneous population estimates can result from soil cast indices because winter activity depends on the initial winter population, overwinter survival, duration of continuous snow cover, and the presence of frozen soil beneath the snowpack (Reid 1973:RGA).

Open Hole

The open hole technique is used to express relative population abundance or to evaluate postcontrol treatment success (Miller and Howard 1951:DC; Richens 1968:DC; Barnes and others 1970:DC; Birch 1978:DC). Certain behavioral traits of gophers form the basis for this method's use. The method relies on gophers' solitary habits and on their general tendency to plug holes in burrow systems within 24 hours. Personnel open



Figure 6.—Winter casts often remain intact for several weeks after the snow melts.

marked burrows, then check the number of replugged holes 24 hours later for indications of activity. Control treatment evaluation involves using this survey in establishing pretreatment activity levels, treating burrow systems with some control agent, and then repeating the survey 7 to 14 days later. Reopened holes left unplugged 24 hours after this followup survey probably indicate a dead gopher. Rainy periods may invalidate this technique because gophers may not plug holes when relative humidity at ground level reaches 94 percent or more (Hungerford 1976:FF). Plural occupancy may result in conservative density estimates (Miller 1953:DC; Richens 1968:DC).

Aerial Photography

Low or sparse vegetative cover permits the use of 1:600 and 1:1,200, large-scale, normal color, or infrared aerial photography to make mound counts. Accuracy of this method compares favorably (97 percent) with ground count estimates (Driscoll and Watson 1974:PE).

Trapping Transects

Animals trapped along transect lines provide relative abundance estimates (Keith and others 1959:DC; Hansen and Ward 1966:HRR; Tietjen and others 1967:HRR). Personnel locate tunnels by probing at 3- to 4-inch (8- to 10-cm) intervals along predetermined lengths of transects, then set traps within the tunnels. Captured animals provide an index to area population, and specimens are readily available for life-history studies.

Capture-recapture techniques employ marking live-trapped animals with either metal bands or by toe-clipping on the hind foot (Ingles and others 1949:PE; Andersen and MacMahon 1981:RGA). This technique requires many hours of trapping, but it also provides good information on survivorship and on other characteristics for demographic analysis.

Nearest Neighbor

A Colorado range study used the "nearest neighbor" concept to estimate gopher population densities and to determine the relationship of density to territory size (Hansen and Remmenga 1961:F). The method correlated the number of gophers per acre with the average distance to the nearest four captures. The average distance between catches decreased as density increased. Method results appear similar to those of simple trap-outs. Assumed random distribution can bias this method because populations may exhibit uniform or clumped distributions.

DAMAGE

For many years land managers have recognized pocket gophers as damaging pests. Gophers have been reported to gnaw underground electric cables (Howard 1953:DBM), but vegetation damage is the major problem. *Thomomys*, the most widely distributed genus in the United States, causes the majority of resource damage and economic loss. Six species of *Thomomys* occur in the Pacific Northwest. Among these *T. talpoides*

and the nearly identical *T. mazama* range the widest (Ingles 1965:DT). These two species cause the majority of conifer damage in commercial forest plantations (Capp 1976:DTF).

Agricultural Lands

Agriculturalists first recognized the significance of gopher problems in many root, fruit, and bulb crops (Lantz 1918:DTR; Crouch 1933:DC). Early literature documented canal breaks costing thousands of dollars in crop losses and repairs because of gopher burrowing activities in the banks (Day 1931:S; Scheffer 1931:B; Downhower and Hall 1966:DT). Periodic flooding of cropland often discourages rodent populations, but nonirrigated crops may become particularly susceptible to gopher inhabitation (Scheffer 1931:B). *Thomomys quadratus* caused serious root damage and significant economic loss in Oregon orchards (Wight 1930:RGA). In addition, vast numbers of gopher mounds and dirt heaps on a field can cover large areas of growing crops and later obstruct harvesting operations. As many as 1,200 to 1,500 mounds per acre (3 000 to 3 700 per ha) may occur on a field of average infestation (Scheffer 1931:B).

Rangelands

The abundance of gophers on rangelands can drastically reduce ground cover and herbage production as a result of burrowing, mound building, and foraging (Turner 1973:HRR). Mounds and castings can cover 4 to 10 percent of the ground area (Buechner 1942:HRR; Ellison 1946:S). Where gopher densities are particularly high, displaced soil may cover up to one-fourth of the surface area within 1 year (Turner 1973:HRR). Food availability often determines the foraging range of individual animals. Digging activity and soil disturbances may increase on poor range where a gopher will extend its burrow system in search of more vegetation (Scheffer 1931:B; Moore and Reid 1951:HRR).

Pocket gophers harvest and bury large quantities of vegetation during foraging activities and can greatly influence plant composition and density. On a range in Texas, Buechner (1942:HRR) found that gophers brought more than 5,600 lb/acre (6 300 kg/ha) per year to the surface and covered over 8 percent of the vegetation annually. A Colorado study revealed that gophers reduced the available herbage by as much as 20 percent or almost 80 lb/acre (90 kg/ha) (Turner 1969:HRR; Turner 1973:HRR). Andersen and MacMahon (1981:RGA) concluded that *T. talpoides* in Utah consumed 30 percent or more of the net annual primary production allocated to belowground plant parts. In Utah, Richens (1965:DC) found that areas under gopher control treatment produced two to three times more plant tissue than nearby uncontrolled areas.

Feeding activities and soil disturbance subject various plant species to different selective pressures (Buechner 1942:HRR). High gopher densities generally suppress perennial forbs and grass species even though annual weeds and grasses continue to thrive (Moore and Reid 1951:HRR; Turner 1969:HRR; Laycock and Richardson

1975:HRR). Some plants such as slender wheatgrass (*Agropyron trachycaulum*) and mountain brome (*Bromus carinatus*) may respond favorably to pocket gopher activity and benefit livestock (Turner 1973:HRR). Other potentially harmful plants such as orange sneezeweed (*Helenium hoopesii*), a species poisonous to sheep and unpalatable to cattle, may increase as a result of gopher activity (Turner 1969:HRR).

The degree of gopher influence on herbage composition depends on soil and vegetation characteristics and livestock grazing intensity over time (Moore and Reid 1951:HRR; Turner 1969:HRR). Buechner (1942:HRR) found gophers most abundant on overgrazed ranges and on heavily used areas where vegetation remained in early successional stages.

Gopher activity can aggravate impacts of grazing livestock and further contribute to range deterioration. Burrowing and mound building prevented the return of fescue (*Festuca idahoensis*) in Utah cattle enclosures (Tevis 1956:DTF). Moore and Reid (1951:HRR) found that gophers prevented perennial grasses from reestablishing on overgrazed ranges in Oregon. They also noted that overgrazing on poor range required gopher control for range improvement, but thought that control probably was unnecessary for meadows in fair condition.

Alternatively, in Kansas the plains pocket gopher destroyed undesirable weeds by feeding and digging (Downhower and Hall 1966:DT). Hall (1955:GR) discussed how gophers might actually improve conditions for grass return on overgrazed ranges. In the absence of livestock grazing, gophers destroyed large-rooted weeds and enabled grass reestablishment. Decreases in gopher abundance might result from the improvement of range conditions and the exclusion of livestock grazing. Similarly, on the subalpine grasslands in Utah, Ellison and Aldous (1952:HRR) found that grasses and sedges increased in the presence of gophers and the absence of cattle.

Gopher digging activities may affect development of rangeland soil (Grinnell 1923:S; Turner 1973:HRR). The rodents constantly mix earth during excavation activities. Richens (1966:B) estimated that they displaced 30,000 lb soil per acre (34 000 kg/ha) on mountain rangeland each year. Gophers may enhance range productivity by loosening and softening heavy clay soils previously compacted by livestock (Ellison and Aldous 1952:HRR; Ratliff and Westfall 1971:S). They may render ground more fertile through disturbance if minerals, interstitial air, and water become more available to plants (Grinnell 1923:S; Downhower and Hall 1966:DT). Tevis (1956:DTF) reported that gopher digging on overgrazed ranges in Utah left bare mineral soil exposed, creating an ideal seedbed for conifers. However, he noted later that gophers were destructive to seedlings trying to establish on the range.

The increased permeability and porosity of soil caused by this rodent's activity may favor water conservation (Turner 1973:HRR). Conversely, burrowing may cause accelerated soil erosion through the formation of erosion gullies (Tevis 1956:DTF). The soil piled on the surface weathers sooner and may contribute to increased sedi-

ment load in the watershed (Frank and others 1975:S). Free-flowing water channeled by castings can initiate erosion scar formation, and water flow through burrows can hasten soil breakdown (Day 1931:S). Marston and Julander (1961:HRF) found that pocket gophers reduced perennial plant cover in an aspen-cleared plot in Utah. They thought the remaining ground cover would not provide sufficient protection to the soil from overland flow and might enhance erosion.

Gopher influence depends on characteristics of individual areas and the intensity of land use. Ellison (1946:S) reported that gophers on the Wasatch Plateau in Utah helped to accelerate erosion, but overgrazing by cattle on the range caused the majority of the problems.

Forest Lands

On forest lands, intensified reforestation efforts throughout the West reveal that gophers can seriously hinder successful seedling regeneration (Moore 1940:DTF; Dingle 1956:DTF; Hermann and Thomas 1963:HRF; Barnes and others 1970:DC; Hooven 1971:DTF).

Gophers destroyed two-thirds of the trees on study plots in Oregon's 15,000-acre (6 100-ha) Cave Mountain burn within 3.5 years (Crouch 1971:DTF). Damage resulted in the loss of the \$200,000 planting cost and an estimated loss of 450,000 bd.ft. (\$9,000) (Canutt 1970:DTF). On the smaller, 170-acre (69-ha) Dugout Lake burn, pocket gopher depredation basically eliminated stocking (Barnes 1973:DTF). Damage control after replanting the area in 1969 included two \$3,500 gopher-baiting programs. Costs reached \$19,000 as of 1973 for both plantings and damage control.

Pocket gopher damage currently affects at least 300,000 acres (121 000 ha) of USDA Forest Service lands (Barnes 1978:DC), and rates as a major forest animal pest. Most damage is reported on ponderosa pine (*P. ponderosa*) plantations (Dingle 1956:DTF; Crouch 1969:DTF; Hooven 1971:DTF; Barnes 1973:DTF; Barnes 1974:HRF).

The response of populations resulting from forestation practices will vary between habitat types and with silvicultural practices. Clearcuts may support large populations, and damage often is acute in these areas (Williamson and Minore 1978:DTF; Minore 1978:DTF). Barnes (1974:HRF) found pocket gophers less abundant but widely distributed through shelterwood cut areas. Delayed reforestation after harvest poses the most serious problem through creation of open disturbed areas. These areas provide ideal gopher habitat, and as populations build with the establishment of profuse vegetation, the problems of reforestation increase (Barnes 1974:HRF; Capp 1976:DTF; U.S. Department of Agriculture 1979:DC). Pocket gopher problems will probably increase in all conifer stands, although future problems will intensify in true fir stands (Borreco 1982, personal communication) and lodgepole pine (*P. contorta*) because of increased logging activity (U.S. Department of Agriculture 1979:DC). Some of the most serious impacts to reforestation take place when gophers, deer, elk, cattle, or beaver impact areas simultaneously (Evans and others 1981:DTF).

Identification and Description

Conifer damage by pocket gophers results from root pruning, stem clipping, girdling, partial removal of stems and crowns, or total removal of small seedlings (Barnes 1973:DTF) (fig. 7). Gophers can seriously affect conifer regeneration up to 10 years after planting (Dingle 1956:DTF). The most serious damage, however, occurs within the first 2 or 3 years, and damage to small seedlings often results in mortality (Crouch 1971:DTF; Hooven 1971:DTF). Crouch (1971:DTF) reported that total seedling removal caused 76 percent of the tree loss in the Cave Mountain, Oreg., burn study area.



Figure 7.—The root system of an established seedling is nearly destroyed by the pocket gopher.

Extensive gopher damage to conifer seedlings most commonly occurs in the absence of preferred vegetation (Burton and Black 1978:FF). Damage to trees occurs year-round but most frequently in winter. Scarcity of herbaceous vegetation forces gophers to feed above ground beneath the snowpack (Crouch 1969:DTF, 1979:DC; Canutt 1970:DTF; Barnes 1973:DTF; Buchner and Rorabaugh 1979:DTF). Barnes (1974:HRF) found that 90 percent of the gopher-caused tree damage on his

study area occurred in winter with virtually all damaged trees dying. Allen and others (1978:DC) found gopher damage greatest during winter on the Targhee National Forest, with the majority attributed to crown clipping. Tree girdling occurred beneath the snowpack to a height of 3.3 to 3.9 ft (1 to 1.2 m). Hooven (1971:DTF) observed girdling damage in lodgepole pine to a height of over 7 ft (2.1 m). Extensive winter damage results in obvious white tree trunks showing after snowmelt (Barnes 1973:DTF).

Teeth marks on trees and shrubs characterize pocket gopher damage. Winter soil casts, mounds, or runways occasionally surround injured trees. Removal of a young seedling may result in a mound or plug or in no visible sign at all (Canutt 1970:DTF).

Porcupines (*Erethizon dorsatum*) or mountain beaver (*Aplodontia rufa*) were blamed for some pocket gopher damage in the past (Crouch 1969:DTF). Porcupines generally limit barking to the outer wood surface, while gophers often gnaw deeply into the wood of old seedlings and young saplings (Canutt 1970:DTF) (fig. 8). In addition, porcupines leave discarded fragments of outer bark at the base of the damaged tree while gophers do not.

Evidence of root pruning may not become apparent until the tree shows visible signs of stress. Trees may tilt and foliage may turn brown over time (Canutt 1970:DTF).

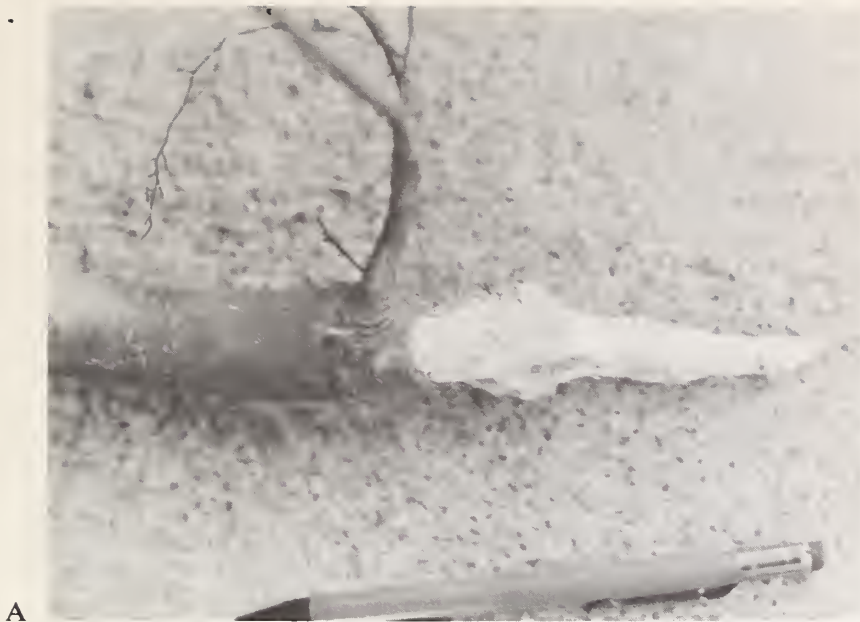
Tevis (1956:DTF) reported that burrowing gophers left the roots of red fir seedlings exposed with extensive damage resulting. However, Barnes (1973:DTF) and Turner (1973:HRR) thought that root exposure and damage resulting from burial by mounds and winter casts constituted lesser forms of injury.

CONTROL

The task of computing an economic analysis of pocket gopher damage and control remains difficult. Lack of data and detailed damage surveys creates a problem in estimating the extent of actual gopher impact on managed lands. Limited funding and a need to prioritize control areas complicate management decisions.

Presently, economic concern is primarily on gopher impacts to harvestable forest lands. Growing demands for wood products and subsequent inflation of timber values provide the basis for this concern.

Increased concern by land managers led to the formation in 1973 of the Northwest Forest Pocket Gopher Committee (NWFPGC) to study damage problems and promote solutions. In 1974, this group affiliated with the Oregon-Washington Silvicultural Council of the Western Forestry and Conservation Association. In 1975, the committee developed a questionnaire designed to determine the extent of gopher damage in the Pacific Northwest and the efforts to control it. Results of this survey showed that the majority of damage occurred on forest lands east of the Cascade Crest in Oregon and Washington. Almost 80 percent of those surveyed thought that damage over the coming 10 years (1975 to 1985) would remain constant or increase. The group indicated that control measures involved only 10 percent



A



B

Figure 8.—(A) The pocket gopher gnaws deeply into the wood and consumes everything, leaving no residue on the ground around the tree. (B) Porcupines chew off the bark but do not gnaw into the wood. They leave shreds of bark on the ground around the tree.

of the gopher-affected acreage; 80 percent of those administering control programs thought their efforts insufficient. Factors contributing to poor success included inadequate budget, personnel, equipment, and control techniques, and the inability to detect damage.

A recently formed USDA Forest Service "activity review team" looked at gopher-reforestation issues to find more workable solutions (U.S. Department of Agriculture 1979:DC). Under the team's influence, western Forest Service Regions 4 and 6 compiled available data on total area planted, seedling survival, area subjected to gopher control, and all associated costs for these programs. This type of comprehensive review in each region could serve as a starting point.

On forest lands control difficulties intensify when managers fail to anticipate damage while planning timber harvest (Barnes 1974:HRF; Buchner and Rorabaugh 1979:DTF). Early recognition of potential problem areas and prompt application of direct or indirect control could prevent or reduce losses (Barnes 1973:DTF; Capp 1976:DTF; Buchner and Rorabaugh 1979:DTF). Conifer losses in some areas may gradually increase enough to cause reforestation failures or restocking delays. Managers should monitor suspected problem areas and determine the need for damage control annually (Crouch 1979:DC). Cooperation among land managers, including wildlife biologists, will help prevent

or decrease animal damage conflicts (Capp 1976:DTF; U.S. Department of Agriculture 1979:DC). Kinds of control vary with area size and situation. Successful control must exceed the naturally high annual gopher mortality rates (70-75 percent) (Hansen 1960:RGA). Capp (1976:DTF) recommends a population reduction of 90 percent. Managers must become familiar with the advantages and disadvantages of techniques. On rangelands, studies document both positive and negative influences of burrowing gophers, but the necessity for control efforts often remains unclear. Where they are integral components of range communities, the gophers' influence on habitat is difficult to evaluate apart from other interacting segments of the ecosystem. Personnel need to define the relationships between the amounts of forage consumed by gophers and the costs of control. In addition, factors that tend to naturally control or minimize the impact of damage need consideration. Gophers are less frequently a problem on well-managed rangelands. Control is more commonly recommended for improvement of deteriorated range than for maintenance of range in fair or good condition (Tietjen 1973:DC).

Alsager (1977:HRR) outlined a method for determining rodent impact to net vegetation production, and for analyzing costs and benefits of control. The technique requires intense labor effort but may warrant further evaluation.

Cost

The Pocket Gopher Reforestation Activity Review Team reported that the cost of contracting for rodent control doubled in the past few years (U.S. Department of Agriculture 1979:DC). Birch (1982, personal communication) concluded from a 1977 study that a 1.69:1 cost-benefit ratio existed on the Ashton Ranger District, Targhee National Forest, Idaho. Subsequent contract bidding competition reduced the cost of treatment. Present treatment costs range from \$20 to \$25 per acre (\$50 to \$62 per ha) for 2 years of treatment after planting, to \$40 per acre (\$100 per ha) for 7 years of protection. Birch (1978:DC) prepared guidelines for organizations wishing to initiate contract baiting control. Costs often increase because seedlings may remain vulnerable to gopher depredation up to 10 years, and many require treatment throughout this period. As reforestation efforts increase to meet expanding demands for wood products, gopher depredation and economic impacts can be expected to intensify (Capp 1976:DTF).

Methods

1. Poison baits.—Poison-coated baits constitute the most commonly used method of gopher population reduction. Baits used with good success include grains such as whole wheat, oat groats, milo, hulled barley, and cracked corn (Marsh and Cummings 1976:DC). In laboratory feeding tests *Thomomys* sp. accepted oat groats and soft milo maize more readily than other grain. Gophers preferred fresh carrots over other vegetables (Ward 1973:FF). Hungerford (1976:FF) found that gophers locate food by odor, and of the food odors tested, fresh carrot juice elicited the most obvious response.

Managers most commonly use strychnine alkaloid poison to coat baits (Capp 1976:DTF; Marsh and Cummings 1976:DC). The poison is fast acting and generally provides excellent control. Success of strychnine alkaloid as a poison depends on consumption of a lethal dose within a short time (Copeman 1957:DC). Animals ingesting sublethal doses may develop a bait aversion instead of dying (Marsh and Cummings 1976:DC). Reasons for consumption of sublethal quantities of poison include: preferences and availability of natural foods in comparison with baits, reduced toxicity of cached bait, and varying levels of bait tolerance by individuals (Barnes, personal communication). Age and associated behavior affect laboratory rodents' susceptibility to various baits (Salmon and Marsh 1979:DC). Although such studies have not been conducted on gophers, these findings may apply.

The amount of bait used varies with local conditions. A high-level strychnine bait (2.8 or 3 percent) used with the burrow builder consistently provides good control (85–95 percent or greater) under a variety of conditions and soil types. High-level strychnine baits are not recommended in hand-baiting because of the poison's hazardous nature (Marsh and Cummings 1976:DC).

Varying State and local laws govern the use of strychnine alkaloid or other toxicants for pocket gopher control. Program restrictions may limit the effectiveness

of present poisoning methods (Barnes 1973:DTF; Capp 1976:DTF; Working Group of the Northwest Forest Pocket Gopher Committee 1976:DTF).

Rodenticide use and possible primary and secondary effects on nontarget species of wildlife generate substantial public concern. Possible baiting hazards to threatened or endangered species influence efforts to control damage. Studies generally indicate minimal danger to other animals from strychnine used in pocket gopher control. Fagerstone and others (1980:BE) found some evidence of nontarget strychnine mortality but no significant adverse effects on population levels. They observed little use of gopher burrows by other species.

Artificial burrow construction may result in exposure of small mammals to bait (Fagerstone and others 1980:BE). Hegdal and Gatz (1976:BE) found that bait applied with a burrow builder significantly decreased nontarget rodent populations on treated areas. Secondary strychnine poisoning might occur if predators consumed bait-killed pocket gophers or their food caches and ingested toxic doses of poison. Chances of this occurring are remote because poisoned gophers tend to die underground (Hegdal and Gatz 1976:BE; Barnes 1981, personal communications). Food caches generally contain greater concentrations of toxin than carcasses, but are less accessible because gophers often store food more than 12 inches (30 cm) below the ground surface. Hegdal and Gatz (1976:BE) concluded that proper strychnine baiting with the burrow builder did not constitute a hazard to seed-eating birds, raptors, and mammalian predators.

The development of increasingly safe and effective baits is becoming more complicated and expensive because of rigid regulations (Marsh and Cummings 1976:DC). In the future, it may be necessary to steer away from heavy reliance on poisons for control. Buchner and Rorabaugh (1979:DTF) suggest integrated pest management as an alternative.

2. Hand baiting.—Hand baiting remains as one of the oldest control methods in common use (Crouch 1933:DC; Crouch 1942:DC; Moore and Reid 1951:HRR; Colorado Cooperative Pocket Gopher Project 1960:DT). The procedure involves locating an occupied burrow system by observing mounds or plugs, finding a main runway by probing, placing toxic bait in the runway with a spoon or mechanical bait dispenser, and covering the opening.

Success depends primarily on the ability to accurately locate burrows and properly insert bait (Buchner and Rorabaugh 1979:DTF). Birch (1982, personal communication) reported that mechanical bait dispensers did not work on the Ashton Ranger District of Idaho because certain soils plugged the apparatus and personnel were unable to tell if bait was applied when the set was made. Crew morale and efficiency depend on weather, gopher activity, and the size of the treatment area. Crews of seven people working under contract may treat up to 90 acres (36 ha) per day depending on their previous experience and on the locale. Incentive pay programs may also serve to improve crew performance (Birch 1978:DC).

Costs of hand baiting relate to crew size and experience, gopher densities, topography, ground cover and debris, and travel distance (Canutt 1970:DC).

Barnes (1973:DTF) noted that baiting by hand or with a mechanical dispenser applies best to small areas or where isolated gopher populations exist. He also indicated that control efficiency dropped in areas greater than 5 acres (2 ha). Birch (1982, personal communication), however, indicated that such a drop in efficiency would be unlikely with contract baiting crews.

3. Burrow builder.—The burrow builder, first developed in California (Kepner and others 1962:DC) and Colorado (Ward and Hansen 1960:DC), provides one of the most efficient means for control on suitable sites (Barnes 1974:HRF; Marsh and Cummings 1976:DC). A tractor-drawn machine pulled across the ground constructs a burrow by means of a torpedo attachment and deposits bait simultaneously. The bait applicator can be used in established pastures, alfalfa and other forage crop fields, vineyards, orchards, or open fields (Marsh and Cummings 1976:DC). Some range and forest lands require the use of a sturdier version of the model (Canutt 1969:DC, 1970:DC; Barnes and others 1970:DC; Barnes 1974:HRF). On the Targhee National Forest, burrow builders constructed by Ghormley Mechanical Industries of Ashton, Idaho, and by Schneid-Miller Industries of Fort Collins, Colo., are currently in use. Birch (1978:DC), who described adjustments made to these machines and to their carriers, reported that a 1977 summer trial with a modified machine demonstrated acceptable burrow construction in rocky soils, brush, sod, slash piles, debris, and on steep slopes. The machine successfully constructed burrows in sod frozen to a depth of 1 to 2 inches (2 to 5 cm). Burrow builders, however, achieve highest success on reasonably firm, moist soils. Artificial burrows will collapse in over-dry soils, and saturated soils tend to interfere with proper machine functioning (Marsh and Cummings 1976:DC).

4. Habitat manipulation.—Land use practices that alter habitat can strongly influence gopher populations. Range or forest management that disturbs soil and/or stimulates the production of herbaceous vegetation often improves habitat for pocket gophers. Early management planning assessment of potential gopher damage may enable effective, coordinated habitat manipulation as part of reforestation or other management goals (Volland 1973:HRF; Barnes 1974:HRF). Volland (1973:HRF) described the relationships between numerous community types and gopher densities in central Oregon, and suggested tree harvest methods and preventative management practices to minimize damage in different plant communities.

Modification of site preparation and logging practices in reforestation may discourage the establishment of favorable gopher habitat. In some cases, limiting site preparation to individual planting sites rather than disturbing entire areas will minimize soil disturbance. Barnes (1974:HRF) thought his method practical in brush fields, although problems with other animals such as rabbits and hares may increase. In some cases, however, minimal soil mixing may inhibit adequate natural restocking, or competition between pine, browse, and grass species may make it impractical (Buchner and Rorabaugh 1979:DTF). Packer (1971:DC) described other techniques of site preparation to minimize soil disturb-

ance, including the clearing of tractor-cut strips and methods of terracing. The cutting of strips, however, may not reduce gopher damage problems, and in some cases may even increase them (Anderson 1982, personal communication).

Uncut buffer strips, 500 to 700 ft (152 to 213 m) wide, adjacent to logged areas, may delay or minimize gopher invasion from neighboring sites (Barnes 1974:HRF). Buffer strips of this size become impractical as acreage occupied by gophers increases and the value of wood products rises (Capp 1976:DTF). In addition, Crouch (1982, personal communication) observed pocket gophers traveling more than 500 ft (152 m) on logging roads between adjacent clearcuts. Thus, invasion may occur regardless of buffer strips.

Timber harvest should be designed for minimal canopy disturbance (Capp 1976:DTF). Barnes (1974:HRF) reviewed several studies indicating that the reduction in overstory canopy stimulated production of preferred gopher vegetation. He suggested that partial cuts should replace clearcutting whenever feasible. Shelterwood cuttings in lodgepole pine and mixed conifer habitat on the Deschutes National Forest, Oreg., showed promise for avoiding some of the regeneration problems experienced on wildfire and clearcut areas (Barnes 1978:DC). On the Dead Indian Plateau, Oreg., the best natural regeneration occurred when 60 percent of the overstory canopy remained after planting. Personnel estimated this optimal percentage given other variables affecting regeneration, but pocket gopher damage constituted a major concern. Buchner and Rorabaugh (1979:DTF), examining a number of harvest methods, indicated that properly employed selective cuts might result in excellent natural regeneration to the extent that gopher depredation would not cause a substantial impact.

Replanting should occur as soon as possible after harvest. Planting more and larger fast-growing stock can minimize seedling susceptibility to mortality from gophers. In addition, sites can be prepared for machine baiting by manipulating debris and planting trees to allow spaces large enough to accommodate a burrow builder (Capp 1976:DTF).

Herbicide reduces a habitat's carrying capacity for gophers by altering the plant community composition. On rangeland, treatment with 2,4-D provided dramatic reductions in forb species, and subsequent decreases in gopher populations followed (Keith and others 1959:DC; Hansen and Ward 1966:HRR; Tietjen 1973:DC; Hull 1971:DC). Extensive feeding trials revealed that direct ingestion of 2,4-D sprayed on grasses and forbs resulted in no apparent toxic effects to gophers (Tietjen and others 1967:HRR).

In forest environments, complete control of vegetation with atrazine, simazine, and 2,4-D reduced gopher activity to one-tenth of that on untreated areas. In addition, competition with conifer seedlings for soil moisture was reduced and seedling survival increased (Black and Hooven 1977:DC). Crouch and Hafenstein (1977:DC) found that aerial applications of atrazine improved survival of ponderosa pines that were subjected to competition from herbaceous vegetation and depredation by

pocket gophers. Crouch (1979:DC) found in south-central Oregon that one or two fall applications of atrazine to 1-acre (0.4-ha) plots of ponderosa pine significantly increased seedling survival and growth after 10 growing seasons. His results strongly indicated that atrazine treatments over larger areas would further increase effectiveness.

Pocket gopher populations generally do not decline in response to vegetation alterations for at least 1 year after control treatments. Managers should delay forest regeneration attempts accordingly; otherwise, gophers are likely to increase feeding activity on planted conifers as other foods become unavailable (Black and Hooven 1974:HRF, 1977:DC; Burton and Black 1978:FF; Crouch 1979:DC).

Because control via vegetation alteration is short-lived, manipulation will probably be most valuable when used to improve the efficacy of direct control or to establish physical barriers to gopher dispersal. In USDA Forest Service Region 5, integrated control approaches combining habitat manipulation with baiting programs commonly occur. Baiting with increased stocking levels has also been used to resolve gopher damage problems. Combining methods of control may be expensive but necessary in many areas (Minore 1978:DTF). Because of growing concerns of potential human and environmental hazards, future use of herbicides and poison baits may be severely restricted.

5. Kill trapping.—Managers use kill trapping most extensively in small affected areas or where very low gopher populations occur. Trapping adequately substitutes for poisoning in terms of effectiveness, but the technique is more labor intensive and expensive (Crouch 1979:DC). Frank (1975:DC) did not consider kill trapping the most humane way of killing animals. Managers use trapping, in conjunction with other control methods, to remove any of the rodents missed in the initial control operation, to stop reinvasion at the onset, or as a research tool (Tietjen 1973:DC). Trapping incurs some nontarget mortality, but does not significantly affect other small mammal populations (Frank 1975:DC).

Of the variety of traps used, Tietjen (1973:DC) reported the Macabee type worked best for northern pocket gophers. In southern Alberta, Alsager (1977:HRR) evaluated a number of traps and achieved best success with the Guardian gopher trap. Frank (1975:DC) prepared a set of guidelines for conducting a trapping program.

Various authors discuss trapping techniques and related success (Dixon 1922:DC; Crouch 1933:DC; Storer 1938:DC). Because of characteristic behaviors of gophers, there is some controversy over whether to close openings above sets or to leave them open, exposed to light and air. Gamboa (1975:BE) tested the efficiency of both trapping methods and found no significant difference between them. He warned, however, that trapping efficiency may reflect species-specific behavioral responses.

6. Wire caging and plastic seedling protectors.—In the past, managers protected young trees from gopher damage by enclosing individual seedlings in wire cages.

On the Dead Indian Plateau, Oreg., caged seedlings grew better in some instances than bare-root and container-grown seedlings. The cages provided protection from snow, litter fall, and foraging animals (Williamson and Minore 1978:DTF). However, managers did not consider caging practical because of expense. Industry subsequently developed plastic mesh seedling protectors such as "Vexar" to replace wire caging (Campbell and Evans 1975:DC) (fig. 9). Vexar effectively reduced gopher damage to conifer seedlings over unprotected seedlings (Anthony and others 1978:DC). In 1977, two 20-acre (8.1-ha) plots were planted with Vexar-protected seedlings on the Ashton Ranger District, Idaho. To date, both still show 96 percent tree survival and additional growth, as compared to 30 percent survival of nonprotected trees. In addition, 200 acres (81 ha) contract-planted in 1979 also remain protected from depredation. However, associated costs are three times higher than contract control by baiting (Birch 1982, personal communication). Although expensive, this procedure should be considered when there are environmental hazards associated with baiting or where a long-term commitment to rebaiting cannot be assured (Barnes and Anderson 1982, personal communication). Problems associated with this method, other than cost, may include: breakage; compression of the tubing by extreme cold, snow, and frost heaving; and deformity of terminal buds and roots protruding through mesh openings (Anthony and others 1978:DC).



Figure 9.—Seedling protected by a Vexar tube.

7. **Exclosures.**—Exclosures protected study plots from invading gophers with variable success (Horn and Fitch 1942:HRR; Ellison and Aldous 1952:HRR). Workers, however, place little value on exclosures for real operational control. Small-mesh wire, sheet metal, or concrete fencing may be effective in local situations. For best protection from overland and subterranean invasion, fencing should extend 2 ft (0.6 m) below ground surface and 1 ft (0.3 m) above ground depending on expected snow depth (Cummings 1962:DC). Cummings reported that fencing with wire mesh or concrete deterred burrowing in canals or ditches, although fencing involved high costs.

8. **Gas cartridges.**—The placement of gas cartridges in pocket gopher burrow systems provides one alternative to baiting. But the technique is costly and relatively ineffective because gophers have such long burrow systems (Rost 1978:DC). Methods previously discussed show greater promise for future use, although this method of control could be applied in campgrounds or situations where other toxicants or trapping techniques are undesirable (Borrecco 1982, personal communication).

Timing of Treatment

Successful damage control requires organizational commitment, persistence, and the timely coordination of all regeneration practices. On forest plantations, time-of-treatment decisions must take into account density, size, and distribution of existing tree stock, as well as pocket gopher abundance. The entire area occupied by gophers must receive treatment and, if necessary, periodic retreatment (Moore and Reid 1951:HRR; Richens 1965:DC; Allen and others 1978:DC). The administration of control treatments must occur at appropriate times to achieve maximum population reductions. Managers should concentrate efforts on achieving lowest gopher densities during the seasons of highest probable depredation. Allen and others (1978:DC) thought treatment should take place before the young dispersed or during the winter season. Buchner and Rorabaugh (1979:DTF) stated that for maximum success, toxic baits should be applied when animals are most active and preferably before parturition. Barnes (1974:HRF), however, recommended fall treatments because earlier treatments did not adequately protect areas from rapid reinvasion. Gophers exhibit strong tendencies to rein-vade areas newly vacated after control (Barnes 1974:HRF). Spring baitings or less frequent applications may suffice on sites with low reinvasion potential or supporting low gopher populations (Barnes and others 1970:DC). Treatment extending 60 ft (18 m) into a plantation perimeter could minimize reinvasion after poisoning (Allen and others 1978:DC).

In areas of heavy infestation, Birch (1978:DC) recommended fall baiting with a mechanical burrow builder before planting, followed by hand baiting for two subsequent summers to allow adequate establishment of young plantations. However, managers must monitor sites annually thereafter and promptly re-treat sites showing reinvasion.

Miller (1948:B) found control on agricultural lands best after the first heavy rains of autumn. Lower vegetation exists, gophers accept baits more readily, and workers locate runways and mounds more easily during this time. Control effectiveness increases in the fall because it precedes the winter and spring breeding seasons. Summer and fall usually are poor times for control on nonirrigated lands because gophers become less active and vegetation may obscure mounds, making probing difficult.

Gopher population size dictates the number and kind of treatments necessary (Barnes 1974:HRF). Any technique depends on variables that may include: the physical restraints of the environment, especially soil and topography; lack of quality conifer seed; budget restraints; insufficient personnel to administer programs; equipment; and ecological or political consideration (Tietjen 1973:DC; Barnes 1974:HRF; U.S. Department of Agriculture 1979:DTF).

RESEARCH NEEDS

A strong need exists to develop new methods and refine existing techniques for management of pocket gophers. Recently in the Western United States, the Pocket Gopher-Reforestation Activity Review Team (U.S. Department of Agriculture 1979:DC) created procedures for assessing gopher damage, identifying related problems and issues, evaluating control efforts, and making recommendations to guide future research and control. To date, the team has reviewed management and reforestation activities in USDA Forest Service Regions 4 and 6 only, but considers the findings representative of all Western States. The group identified a number of areas and issues in need of attention. Many of these are included in this section.

Improved solutions to gopher damage prevention and control require more information than is presently available. In many areas, problems are evident, but detailed surveys documenting damage are lacking. Budget limitations make it necessary to prioritize research needs and to determine areas where control is most important. Relationships between gopher depredation and economic loss must be evaluated on different areas to analyze the long-term costs and benefits of control and to choose techniques most warranted.

Control Methodology

1. **Response to habitat manipulation.**—Indirect control via habitat manipulation has potential use, but further information is necessary to evaluate how gopher populations will respond to habitat changes resulting from herbicides, various silvicultural systems, and various site preparation techniques. On most areas, there is a shortage of information identifying the forest communities and situations where preventive management could be most effective (Barnes 1982, personal communication). Development of general criteria to foretell problem areas might be valuable for land managers who are faced with difficult decisions in land-use or harvest-planning stages. Clearly defined relationships between

gopher densities and specific habitat characteristics do not always exist (Volland 1973:HRF; Anderson 1976:HRF; Youmans 1979:HRF; Buchner and Rorabaugh 1979:DTF), but certain habitats can generally be correlated to high and low gopher populations. However, it is still necessary to evaluate each situation individually and maintain past and future studies for use as guides.

2. Plastic seedling protectors.—Further evaluation is needed on protective tubing such as Vexar. Although this method is promising, further improvements in preparation, transportation, and planting of enclosed seedlings are necessary to make the procedure more economically efficient (Anthony and others 1978:DC). Additional studies might determine whether this type of protective tube adversely affects seedling root development and tree growth.

3. Poison baits.—The development of new toxicants that might prove more effective, specific, or safer to people and nontarget wildlife is considered important. The best time for baiting treatments in different areas is still uncertain. The possibility of winter control and bait acceptance needs further study. Continued studies are needed of factors related to baiting mortality, including bait attractiveness, toxicity of poison, causes of varying rodent susceptibility, and bait duration. In 1978, Weyerhaeuser researchers looked at the possibility of enclosing baits in polyethylene bags (bagged bait) to extend duration, reduce baiting costs, and further combat reinvasion of existing burrow systems by dispersing gophers. At that time, results of their study seemed promising (Ray 1978, personal communication). Another suggestion involves further development of longer lasting toxic foam or grease for placement in artificial burrows. However, Marsh (1982, personal communication) indicated that past control efforts with existing toxic foams proved relatively ineffective on *T. bottae*. In the future, long-lived baits might meet with opposition from the Environmental Protection Agency.

4. Hazards to nontarget species.—Most studies do not indicate significant control-related hazards to nontarget species, but potential primary and secondary dangers of direct or indirect control practices are a major public concern. This is particularly true when treated areas occur in or near habitats of threatened or endangered species. Federal registration requirements for existing poisons and new toxicants are becoming increasingly restrictive. These same concerns are developing over herbicide use. Such uncertainties may limit future use of the baiting programs managers most commonly rely upon today. For this reason, further evaluation of control agents is necessary, and development of poison-free control measures is emphasized. In addition, opportunities to educate the public on these issues should not be overlooked.

5. Feeding habits.—Quantitative data on gopher feeding habits as they relate to reforestation will help predict problems and develop more effective control methods. Gopher population levels tolerable in conifer plantations should be assessed. Tree stocking levels able to withstand low to moderate gopher depredation need to be determined. Radwin and others (1982:FF) compared essential oil content in ponderosa pine seedlings from nine different regions. Gophers exposed to seedlings showed different degrees of feeding preference. Further study may lead to the discovery or development of naturally gopher-resistant plant species and less vulnerable seedling stock. Such findings might also lead to development of some other gopher repellent or deterrent. However, the adaptable feeding preferences of gophers may limit the potential of this approach.

6. Repellents.—Potential for further development of repellents on forest lands exists. Information detailing subsequent effects to both the gophers and the trees themselves will be needed. In the past, repellents have provided protection for buried cables (Tigner and Landstrom 1968:DC), and Barnes (1973:DTF) cites a report of similar success with fruit trees.

7. Grooming inhibitors.—The use of special tacky substances or wetting agents placed in burrow systems or in the soil might inhibit animal grooming and condition gophers to avoid certain areas, abandon burrows, or become less able to survive. Such sticky substances are yet to be lab-tested, and adequate evaluation for control would require further behavioral research, including studies on food-handling and grooming behavior and the animal's response to these substances. Successful operational control is deemed unlikely.

8. Reproductive inhibitors.—The use of reproductive inhibitors has been considered, but the probability of success is judged low (U.S. Department of Agriculture 1979:DC). Some believe fossorial rodents communicate territoriality and reproductive status via specific chemical signals (pheromones) (Brown 1971:RGA). Employing these as repellents or to inhibit reproduction may be possible, but unlikely.

Integrated Management

The means to effective and efficient control most likely lies in a holistic approach. This entails integrating dynamics of gopher population structure and growth, economic analysis, land management options, and an understanding of forest ecology into an ecosystem-oriented analysis of the problems. On forest sites with serious gopher problems, successful regeneration often depends on the land manager's ability to integrate two or more control methods. In the future, emphasis on various control combinations and prevention of population buildups will increase. Managers should continue to familiarize themselves with pocket gopher problems and the ways to best use existing control techniques.

LITERATURE REVIEW

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A state-of-the-knowledge report on available information on gopher biology, ecology, damage, and control. Habits and related problems are reviewed for gopher species throughout the United States, but attention is focused on pocket gophers in northwestern forest environments. A bibliography containing over 1,000 literature citations is included.

KEYWORDS: pocket gopher, forest plantation protection, plastic seedling protectors, poison bait, burrow builder, tree damage



The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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